"Made available under NASA sponsorship in the interest of early and wide dissemination of Earth Resources Survey Program information and without liability for any use made thereof."

E7.4 - 1 0.6 0.5
CR-138714

Calspan

Technical Report

N74-28838

(E74-10605) S190 INTERPRETATION TECHNIQUES DEVELOPMENT AND APPLICATION TO NEW YORK STATE WATER RESOURCES Interim Report (Calspan Corp., Buffalo, N.Y.) 27 p HC $4.50 CSCL 05B G3/13 Unclas 00605

Original photography may be purchased from
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

color

Calspan Corporation
Buffalo, New York 14221

Formerly Cornell Aeronautical Laboratory, Inc.

COLOR ILLUSTRATIONS REPRODUCED
IN BLACK AND WHITE

Calspan

S190 INTERPRETATION TECHNIQUES DEVELOPMENT AND APPLICATION TO NEW YORK STATE WATER RESOURCES

EREP NO. 391
CONTRACT NO. NAS9-13336

Interim Report
Calspan Corporation Report No. YB-5298-M-1
15 June 1974

Kenneth R. Piech
John R. Schott
Kenton M. Stewart+

Technical Monitor: Larry York
Mail Code TF6
NASA MSC

Prepared For:
NASA MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

Original photography may be purchased from:
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

+Dept. of Biology, State University of New York at Buffalo

Calspan Corporation
Buffalo, New York 14221

ABSTRACT

Correlations between the relative values of the blue and green reflectances of a lake and key water quality indices such as photic zone depth, Secchi disk transparency, attenuation coefficient and chlorophyll concentration have been observed during an intensive aircraft and surface vessel study of Lake Ontario. Determinations of relative values of blue and green lake reflectances from Skylab S190A color imagery are in excellent agreement with values obtained from small scale color imagery from aircraft, and the accuracy of the satellite data is within that required for extrapolation to the key water quality indices. The satellite data have a significant advantage over the aircraft imagery in the ability to depict surface patterns within a large lake, and in the ability to compare a group of smaller lakes on the same frame of imagery.

The prime characteristic of the S190 imagery which is responsible for the measurement accuracy is the resolution capability of the experiment. The two most desirable refinements to the S190 experiment would be increased spatial resolution and regular repetitive coverage. The increased resolution would permit more accurate data processing; more frequent coverage would permit important seasonal water quality comparisons.

1.0 INTRODUCTION AND SUMMARY

This report represents interim documentation of a program to evaluate the potential of sophisticated satellite photography for monitoring selected eutrophication indices of large lakes or systems of lakes. A single satellite photograph (such as that of Lake Ontario in Figure 1.1) provides an impressive display of a water resource which would take many days to sample via surface vessels. For example, a detailed data gathering effort on Lake Ontario would involve transects of about one week in duration. It is therefore important to determine if the patterns and tonal variations contained within such a satellite image can be efficiently converted to parameters which are of lasting value to the limnologist.

The geographical area of our study includes Lake Ontario, and several inland New York State lakes, specifically Conesus, Chautauqua, Honeoye and Canadice Lakes. During the Skylab missions, measurements of chlorophyll concentration and optical data were performed from surface vessels on Conesus Lake. Aircraft imagery were obtained of all the above lakes. Our data base also includes several years of physical, chemical and biological data on Conesus, Honeoye and Canadice Lakes, as well as an extensive set of optical data of Lake Ontario obtained from surface vessels and aircraft imagery during the International Field Year on the Great Lakes (IFYGL).[1]

The latter data base, obtained at monthly intervals during calendar year 1972, indicates that information from small scale aircraft imagery can be related to limnological optical parameters, such as Secchi disk transparency photic zone depth and attenuation coefficient, as well as to important biological parameters such as chlorophyll concentration. Figure 1.2 exhibits typical correlations found between various parameters on the IFYGL effort. The results of Figure 1.2 are of great importance to the present study and are described more fully in Section 2 below.

FIGURE 1.1. SKYLAB S190A IMAGE OF LAKE ONTARIO, 9 SEPTEMBER 1973. TWO FRAMES OF IMAGERY COVERED THE LAKE ON THIS SKYLAB PASS. THE LARGE URBAN COMPLEX ON THE NORTH SHORE IS TORONTO. THE GREEN DISCHARGE ON THE SOUTH SHORE JUST WEST OF THE NIAGARA RIVER IS THE WELLAND CANAL. RESOLUTION ON THE ORIGINAL TRANSPARENCY IS SUPERIOR TO THAT OF THIS PAPER COPY. FOR EXAMPLE, RUNWAYS AT THE TORONTO AND NIAGARA FALLS AIRPORTS ARE WELL DEFINED ON THE ORIGINAL TRANSPARENCY, AS ARE INDUSTRIAL STORAGE PILES IN THE TORONTO HARBOR. THE NIAGARA FALLS AND THE WHITE WATER OF THE LOWER NIAGARA RIVER CAN BE OBSERVED JUST TO THE SOUTH OF THE TWO POWER STATION RESERVOIRS WHICH STRADDLE THE NIAGARA RIVER. THE ALTITUDE FROM WHICH THIS IMAGE WAS TAKEN WAS 270 MILES (435 KILOMETERS).

3

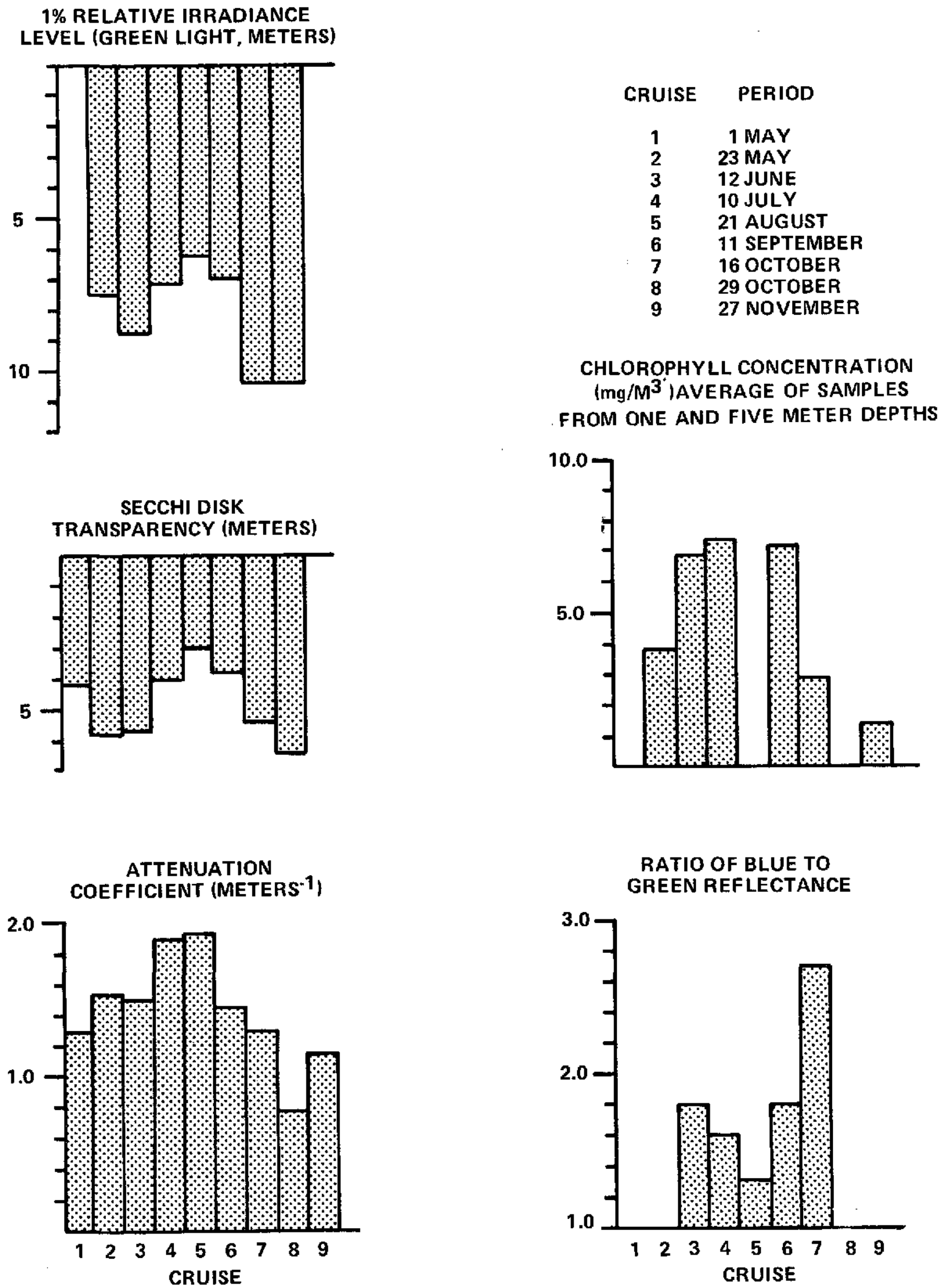


Figure 1.2 COMPARISON OF OPTICAL AND BIOLOGICAL DATA OBTAINED FROM SURFACE VESSEL AND AIRCRAFT MEASUREMENTS DURING THE INTERNATIONAL FIELD YEAR ON THE GREAT LAKES (1972). DATA REPRESENT LAKE-WIDE AVERAGES. CHLOROPHYLL DATA SUPPLIED BY CANADA CENTRE FOR INLAND WATERS.

The requisite data processing for the aircraft imagery involves careful microdensitometric analyses of scene objects, such as shadow areas, in order to remove atmospheric and measurement system variables and thus permit seasonal data comparisons. The data processing is extremely sensitive because approximately two-thirds of the radiance reaching the aircraft is due to atmospheric effects. A small data processing error thus causes a large error in lake reflectance. An even more critical processing problem exists for the data from the satellite imagery.

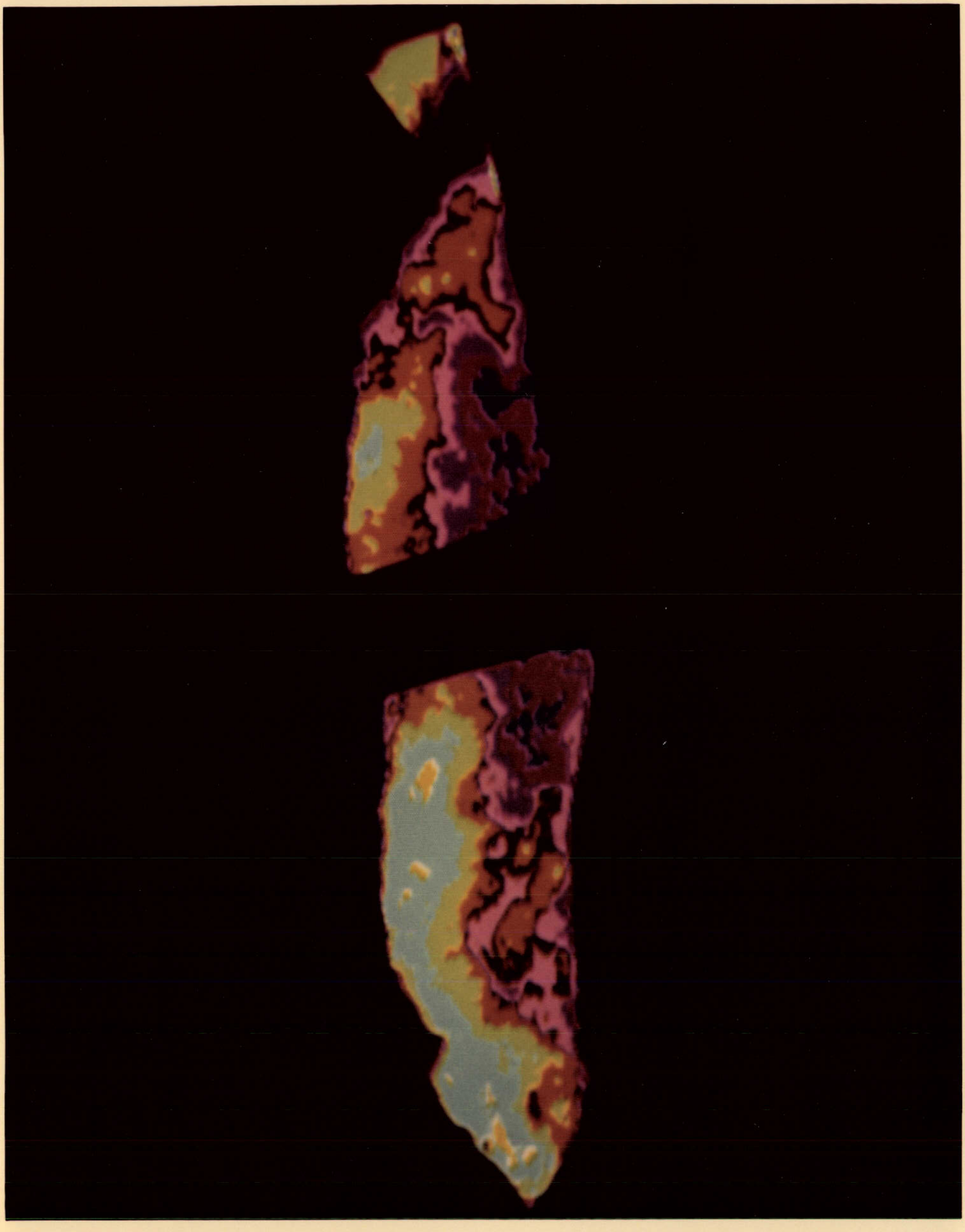
The fundamental question to be answered is whether the satellite imagery can provide data to within the accuracy required for the limnological analyses. The most promising result of our study thus far, and the key result of this interim report, is a demonstration of surprising equivalency between the accuracy of the satellite and aircraft data.

As discussed below, studies on the IFYGL program indicated that the most useful aerial parameter was the ratio of blue lake reflectance to green lake reflectance. The blue to green lake reflectance correlated well with optical parameters measured on surface vessel transects of Ontario. The S190A imagery of Lake Ontario (Figure 1.1) was processed to yield a color encoded display of the blue to green reflectance ratio (Figure 1.3), and the data from this display were compared to aircraft data obtained at approximately the same time. Aircraft data were obtained on two north-south lake tracks between Gold Pt., Ontario and Olcott, New York and between Chub Pt., Ontario and Troutberg, New York. These tracks are approximately one-third of the distance from the western and eastern ends of the lake, respectively. Aircraft altitude was about 10,000 feet (3 km), with the scale of the color imagery about 1:40,000. About fifteen photographs were obtained on each track, each photograph covering an area of about 2.6 square miles (6.6 square km).[2]

Figure 1.4 depicts the satellite and aircraft data obtained on the two tracks. The aircraft point include error bars corresponding to ±12% of the blue to green reflectance ratio, and ±1 mile (1.6 km) in aircraft position.

FIGURE 1.3. COLOR ENCODED DISPLAY OF THE RATIO OF BLUE TO GREEN LAKE REFLECTANCE. THE DARK AREA IN THE MIDDLE OF THE IMAGE IS FILM AREA BETWEEN FRAMES OF THE ORIGINAL IMAGERY; THE DARK AREA ON THE RIGHT HAND SIDE OF THE IMAGE IS CAUSED BY A CLOUD BANK WHICH WAS REMOVED IN DATA PROCESSING. THE COLOR CODE IS:

Color	Blue to Green Ratio
Blue	1.2
Red	1.4
Violet	1.5
Pink	1.8
Orange	2.0
Green	2.4
Light Blue	3.1
Yellow	4.2



4

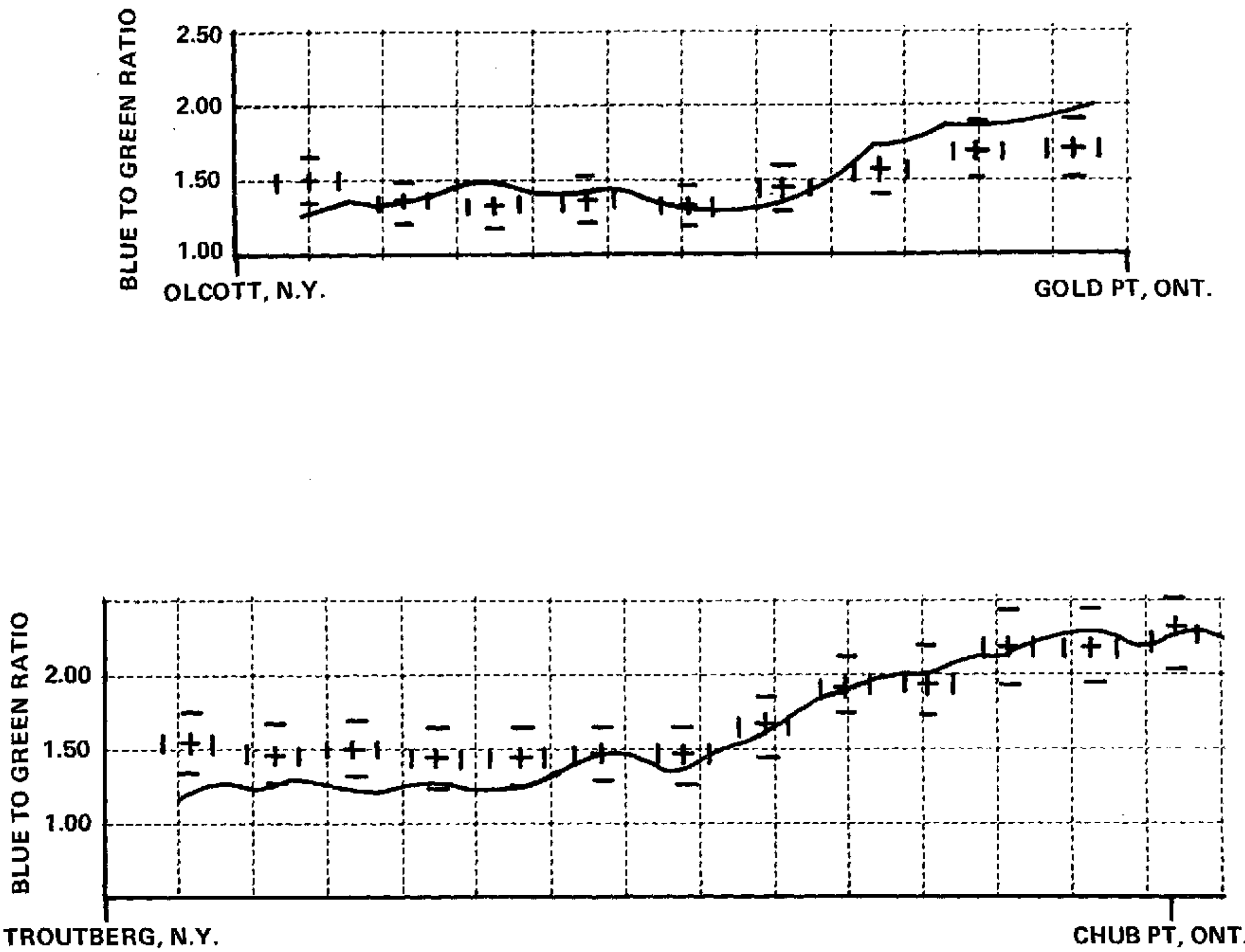


Figure 1.4 COMPARISON OF S190A MEASUREMENTS OF BLUE TO GREEN REFLECTANCE RATIO (SOLID LINE) WITH AIRCRAFT MEASUREMENTS (CROSSES AND ERROR BARS)

The correlation between the data is surprising, and the figure indicates that the S190A color imagery is more than adequate for defining the optical properties of the Lake using relationships similar to those obtained on the IFYGL program.

The satellite data have the additional advantage of providing more comprehensive depiction of lake patterns. Inference of patterns within the lake from multiple aircraft transects is a difficult process. Thus the capability to describe spatial patterns within the lake with greater detail will prove to be of great value.

A key element to data processing of the S190A image was full use of the resolution capabilities of the image. As discussed below, the spatial resolution permitted image calibration through microdensitometry on selected scene objects (large coal piles, airport runways, asphalt areas). We have performed calibration studies on ERTS imagery of Lake Ontario and Antarctica using a cloud shadow technique.[3] The poorer resolution of the ERTS data results in image calibration of lesser accuracy than that obtainable from the S190 data. In addition, the S190 data permits calibration of imagery under more complex atmospheric conditions where spatial variations of the atmosphere are of significance.

There are two major areas of refinement of the S190 data which we would regard to be of first importance. An increase in spatial resolution would permit more accurate and consistent data processing, and would therefore improve the accuracy of the data. An increase in resolution from the present 30 meter range to about 5 meters, if possible, would have significant impact on data processing accuracy. Secondly, a systematic overflight program, similar to the repetitive coverage of the ERTS satellite, would add immeasurably to the value of the satellite data for limnological studies which depend so heavily on temporal comparisons.

2.0 METHODS AND RESULTS

There are three main concepts associated with the program results: (1) What is the relationship between the photographic data and the water quality parameters?; (2) What data processing techniques are required?; and (3) Can the satellite imagery supply the necessary data accuracy, and what constraints do the accuracy requirements impose on the satellite system? Each of these topics will be discussed in turn.

Relationship Between Photographic Data and Lake Parameters

The basis for our comparisons lies in a program conducted during the International Field Year on the Great Lakes (IFYGL).[1,2] During 1972 the IFYGL program engaged in an intensive study of the physical, chemical and biological properties of Lake Ontario. As part of the IFYGL effort, the optical properties of Lake Ontario were investigated on nine, week-long cruises at monthly intervals, during which the following optical measurements were made: Secchi disk transparency, total attenuation coefficient, and subsurface relative irradiance in red, green and blue spectral regions. In addition to the optical measurements made from the surface vessels, small scale (1:40,000) color aerial photography was obtained concurrent with the surface measurements.

The goals of the optical study were to (1) determine the correlations between the various surface optical techniques; (2) determine the extent of any correlation between optical data obtained from ship and aircraft measurements; and (3) provide input data on temporal and spatial lake fluctuations to other IFYGL programs.

The IFYGL data analyses exhibit important relationships between the surface optical data, surface chlorophyll concentration, and the ratio of blue lake reflectance to green lake reflectance as measured from the color film imagery. Figure 1.2 depicts the variations of blue to green lake reflectance, chlorophyll concentration, attenuation coefficient, photic zone depth (in green spectral region) and Secchi disk transparency. The values depicted are lake-wide averages, i.e., averages over all lake stations occupied.

The data of Figure 1.2 indicate a surprising seasonal relationship between the various parameters. The ratio of blue to green lake reflectance is inversely proportional to chlorophyll concentration and coefficient of total attenuation, and directly proportional to photic zone depth and Secchi disk transparency. Station-by-station comparisons of these parameters are more complex, and a discussion of these data will appear in the IFYGL report; however, the data of Figure 1.2 serve to indicate the general quality and character of the relationships involved.

The specific relationship between the various parameters is dependent on physical properties of the lake being studied. For example, Figure 2.1 contains the relationship between blue to green reflectance ratio and chlorophyll concentration for Conesus Lake, as obtained on the Skylab effort. Again, a strong dependency is evidenced with a marked blue-green minimum occurring at maximum chlorophyll concentration, although the specific relationship of chlorophyll concentration and ratio level differs from the Ontario values. The variation occurs because Conesus and Ontario are quite different in physical character. For example, Conesus is darker than Ontario, having a green reflectance of about 2% compared to a reflectance of 3% for Lake Ontario. The darker the lake, the greater the effect chlorophyll absorption can be expected to have on the blue-green ratio. The actual situation is, of course, more complicated than this simple model.

A major area of further research therefore involves generalizing the relationships between aerial and surface data. By way of example, Conesus and Canadice Lakes have approximately the same range of chlorophyll values and Secchi disk transparencies. The Canadice blue to green ratio values which correspond to the Conesus values of Figure 2.1 are: 7 May, 1.5; 19 June, 0.3; 13 August, no data; and, 9 September, 1.4. The close correspondence between the blue-green ratios of Conesus and Canadice, even though specific chlorophyll data for Canadice are not available on these dates, is encouraging. This

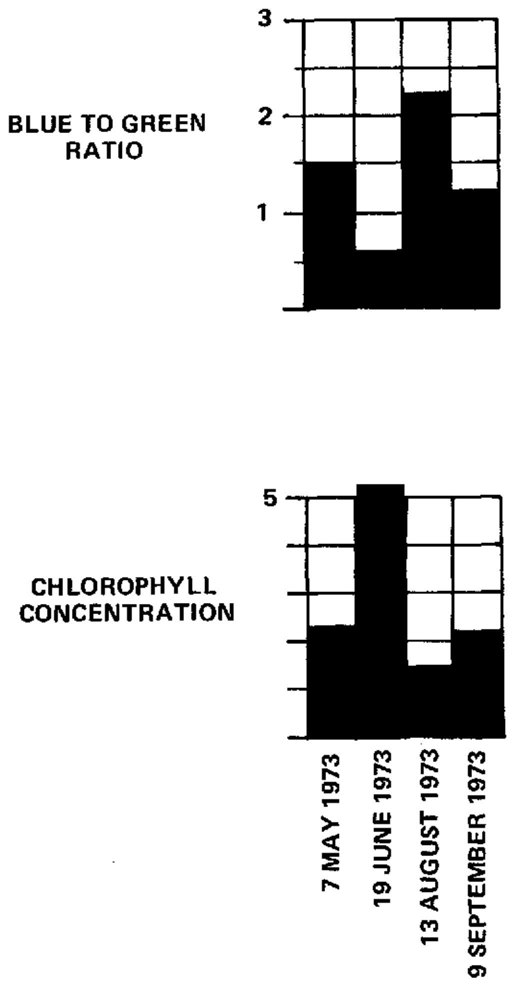


Figure 2.1 COMPARISON OF BLUE TO GREEN REFLECTANCE RATIO WITH SURFACE CHLOROPHYLL CONCENTRATION IN mg/M^3 FOR CONESUS LAKE DURING 1973

correspondence, coupled with the correlation of the aerial and surface data for both Conesus Lake and Lake Ontario, leads us to believe that general relationships valid for lakes of a given trophic classification can be developed, and that such understanding will serve to significantly broaden the scope of application of sophisticated satellite photography. The construction of such an understanding has begun on the present Skylab effort.

Data Processing

The data processing removes effects of peripheral variables, principally effects of film processing and atmospheric and illumination variations, from the tonal variations of the image. Processing effects are easily accounted for through use of the D-log E curves available as standard procedure in the Skylab S190 data package. As a result, film density variations can be translated to changes in relative exposure at the spacecraft.

The resultant exposures, however, must still be related to reflectance values. Such reduction is important because exposure depends on meteorological conditions, altitude of measurement, and illumination conditions such as proportion of sunlight to skylight, and the amount of air light (the contribution to exposure by illumination scattered to the camera by the air column beneath the camera). These effects are depicted in Figure 2.2.

All of these effects can be approximately coupled into three parameters for a given spectral band: α, α', and β.[4-6] The parameter α is proportional to atmospheric transmittance and total (sunlight + skylight) irradiance; α' is proportional to atmospheric transmittance and skylight irradiance; and β is proportional to the amount of air light in the scene. The exposure, E, in sunlight of an object with reflectance R is

$$E = \alpha R + \beta, \quad (1)$$

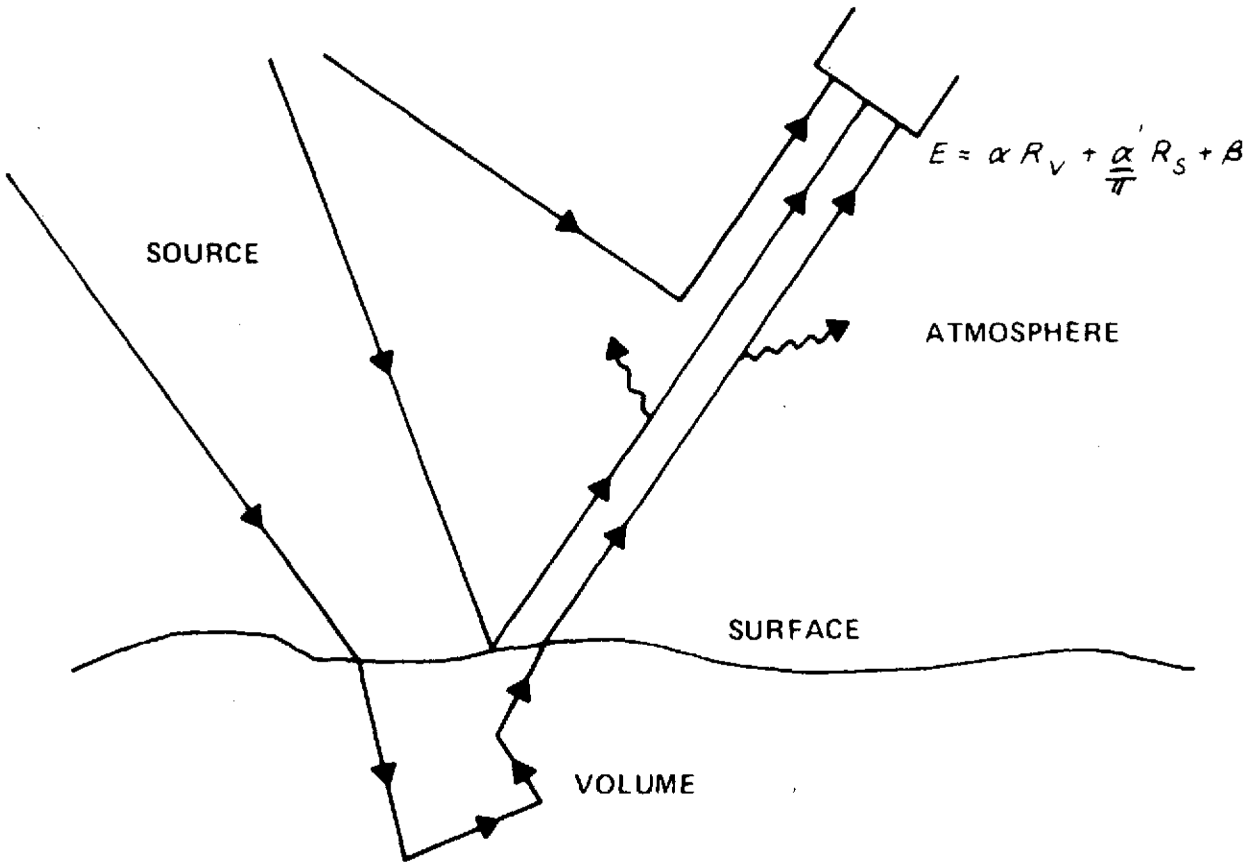


FIGURE 2.2. ATMOSPHERIC AND ILLUMINATION EFFECTS INVOLVED IN ESTABLISHING THE EXPOSURE OF A BODY OF WATER.

whereas the exposure of the same object in shadow, E', is

$$E' = \alpha' R + \beta. \tag{2}$$

Color film measurement of terrain reflectance thus requires knowledge of α, α', and β in each of the three color film bands.

The parameter α' is important because it permits removal of specular skylight reflections from the data. Specular surface reflections of skylight exist at every image point of a body of water. Letting R_V be volume reflectance of the body of water, and R_S the Fresnel surface reflectance (which is known from metric considerations), the exposure from a body of water can be written

$$E = \alpha R_V + \frac{\alpha'}{\pi} R_S + \beta \tag{3}$$

Knowledge of α' thus permits subtraction of specular skylight surface reflection.

The (α, α', β) parameters can be determined in a straight-forward manner using a shadow calibration procedure called the Scene Color Standard (SCS) technique[+]. Calibration is accomplished by densitometry of the illumination discontinuities at shadow edges. It is convenient to write $\alpha = \delta + \alpha'$, where δ is a term proportional to solar irradiance only. The discontinuity measured at shadow edges on two different terrain elements then determines β and δ/α' as follows.

In the sunlight just outside a shadow the exposure E is

$$E = (\delta + \alpha')R + \beta. \tag{4}$$

[+] Patent pending.

The R is the terrain reflectance. Just inside the shadow the exposure E' is given by Equation 2. Equations 2 and 4 yield

$$E = (1 + \delta/\alpha')E' - \delta\beta/\alpha' \tag{5}$$

Equation 5 is a linear relationship between E and E' with slope $(1 + \delta/\alpha')$ and intercept $-\beta\delta/\alpha'$. Two shadows determine the slope and intercept, and hence β and δ/α'. In practice a number of shadows are analyzed, and a least squares fit is made to the data. Figure 2.3 shows typical calibration curves for calibration of a color image at a scale of 1:40,000.

The essential measurement and atmospheric conditions have now been determined. One aspect remains: that of establishing an absolute level of reflectance, akin to laboratory use of a MgO standard or its equivalent. A tar or sheet asphalt scene element in sunlight (roadway, roof) is usually used to establish the value of α and complete the calibration. These elements are used as: (1) their reflectances are spectrally flat; (2) their reflectances remain constant over the year; and (3) their reflectance can be easily estimated or measured. Other objects more appropriate for a particular survey can, of course, be used.

Under conditions where only reflectance ratio values are required, it is not necessary to know the reflectance of a scene element. Instead, the exposure values in one spectral band are plotted against the exposures in another band for a range of flat reflectors. The points obtained are then fit to a straight line in an analysis similar to that shown in Figure 2.3 for obtaining beta. The slope of the line thus obtained is equal to the ratio of the alpha values in the two bands. In practice a slight correction is made to this value to account for the fact that most targets generally assumed spectrally flat are not actually uniform reflectors. Using the relative alpha values obtained in this manner, the reflectance ratios can be obtained. Furthermore, if the reflectance of a terrain object in any one band is known then the absolute alpha value for the band can be obtained as

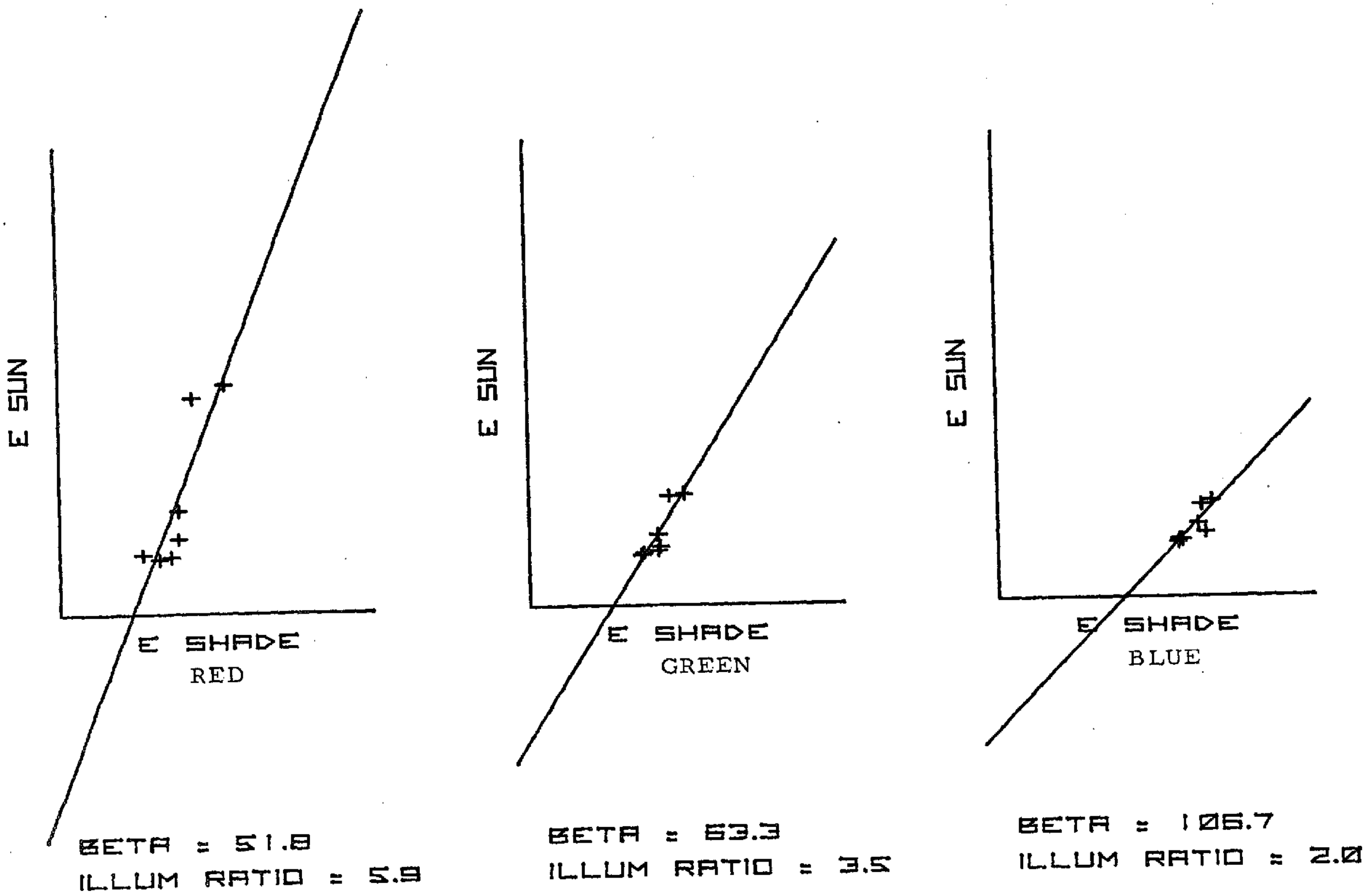


FIGURE 2.3. TYPICAL CALIBRATION CURVES FOR A COLOR IMAGE AT A SCALE OF 1:40,000. THE PARAMETER "ILLUM RATIO" IS δ/α'. (CF. TEXT).

described above. The remaining alpha values can then be obtained from the alpha ratio values.

One minor point needs to be added for completeness. The skylight irradiance inside and outside the shadow is only some portion of the sky dome, k, due to solid angle shielding by the shadowing object. The factor k can be easily determined from metric considerations In practice at, high altitudes only larger buildings suffice for densitometry, and k is practically constant for all the structures utilized. The factor α' in Equations 1, 2 and 3-5 should therefore be replaced by $k\alpha'$ and interpretation of the resulting values of slope and intercept so modified.

At an altitude of 10,000 feet, β can be equivalent to about a 5-10 percent reflector. At low altitudes, β will usually not decrease much below a 2-3 percent equivalent reflector because of camera flare, which is included in the additive light factor represented by β. It must be emphasized that the actual values of β will depend strongly on meteorological conditions, the spectral band (bandwidth, central wavelength) in which the measurement is made, and the flare characteristics of the instrument utilized. Because of the wide variation of β (and also α and α') with atmospheric, illumination and measurement system variables, exposures must be carefully reduced to reflectances for meaningful limnological assessments. The values of β for the aircraft underflight of the Skylab satellite were 5.6% in blue and 3.7% in green. The values of β for the satellite imagery were 11% in both green and blue bands.

The resolution of the S190 experiment is, of course, insufficient to permit shadow densitometry. In this case, reflectances of terrain objects which had been measured both aerially and with ground photometers were utilized for calibration through a least squares fit to the form of Eq. (1). The use of standard targets unfortunately does not permit measurement of α'. In addition, the technique is less accurate under complex atmospheric conditions which change significantly in the spatial regions being studied. Standard targets are required in each "region" of the image in which atmospheric conditions are uniform, and frequently such standard targets are not available. The Skylab imagery of Figures 1.1 and 1.3 contained remarkably uniform atmospheric conditions over the entire lake, simplifying calibration of the satellite imagery. Improvement in the satellite resolution would permit shadow analyses for more accurate and convenient data calibration, hence, our motivation for the refinement of the imagery discussed in the first section.

A photointerpretation console which enables the interpreter to calibrate color film quickly and accurately has been fabricated for the Reconnaissance Applications Section, Rome Air Development Center.[7] A similar console is available at Calspan's Buffalo facility. The console also enables the interpreter to obtain color encoded displays of spectral reflectance ratios from the color imagery. The capabilities of the console were important for the Skylab water quality analyses.

Figure 2.4 contains a schematic of the experimental photointerpretation console. The console provides the imager interpreter with all of the capabilities he presently utilizes; i.e., (1) a variable illumination light table and (2) zoom stereo magnification with reticules and scales for mensuration in a convenient location. However, in addition, (3) a micro-macro densitometer capability, (4) a desk calculator and display capability and (5) a CRT color display capability are provided to quantify and present spectral ratio information to the interpreter. To generate this information another light table (6) is required to photographically copy and develop (7,8) the spectral ratio imagery which is then displayed to the density slicing and color encoding vidicon (9) for display on the color CRT, through a control panel (10).

Results from S190 Analyses

Several years of analyses have been conducted on the lakes discussed above, with the goal of establishing a relationship between aircraft data, and surface optical and biological parameters. The analyses indicate that an important relationship exists between the blue to green reflectance ratio and

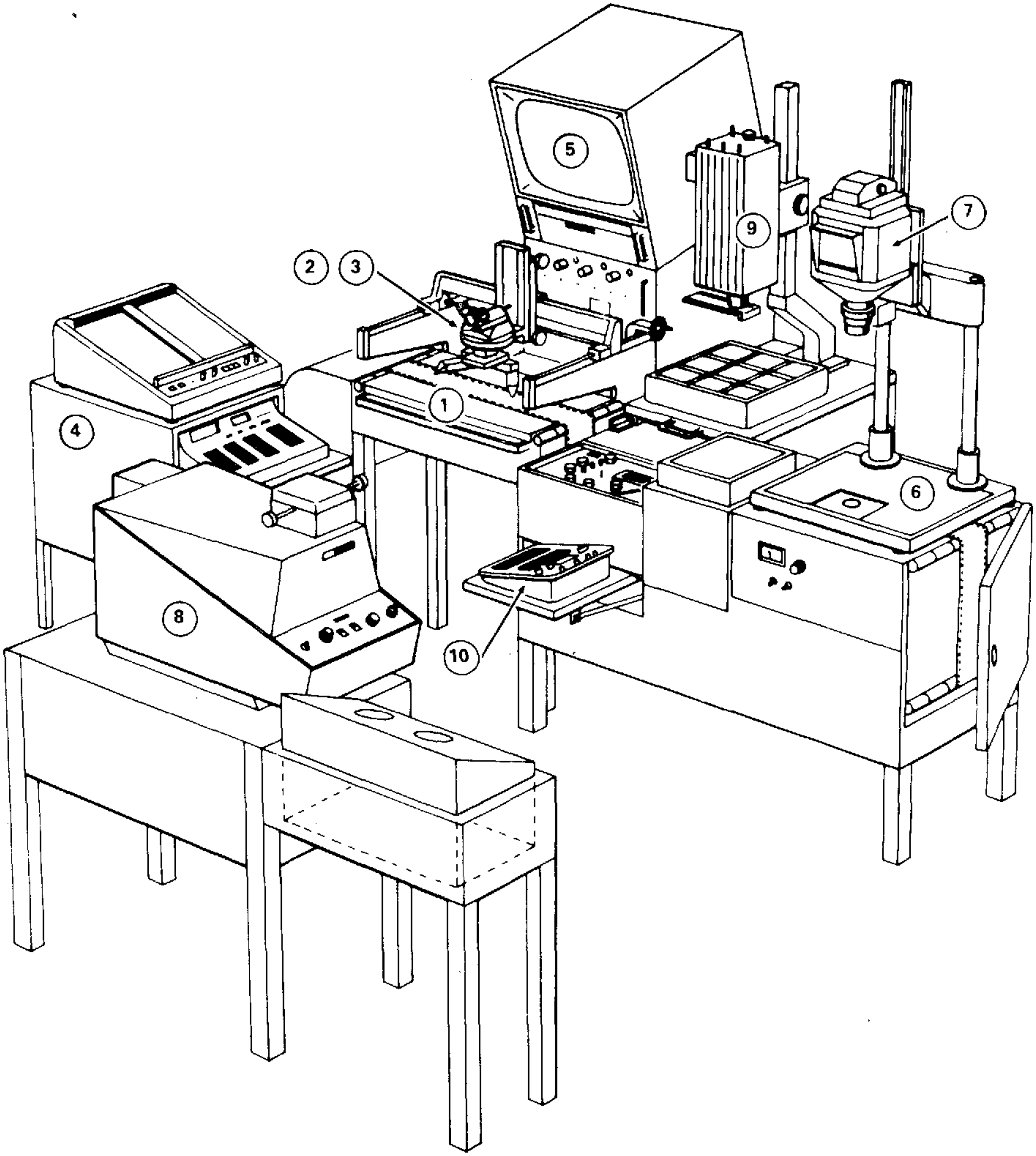


FIGURE 2.4. THE EXPERIMENTAL PHOTOINTERPRETATION CONSOLE. THE CONCEPT AND DEVELOPMENT OF THE CONSOLE WAS SPONSORED BY ROME AIR DEVELOPMENT CENTER, U. S. AIR FORCE.

both optical and biological lake parameters. The most important element in our Skylab study is then to demonstrate that satellite imagery can provide measures of relative blue and green reflectances which are equivalent to those available from aircraft data. Once this equivalency has been established, the conclusions of the previous studies can then be transferred to the Skylab imagery.

The principal interim program results are thus contained within Figure 1.3, the map of blue to green reflectance ratio for Lake Ontario, and Figure 1.4, the comparison of satellite and aircraft data. The average blue to green reflectance ratio for the S190 data of 9 September 1973, as determined on an area weighted basis, is 1.9. It is interesting to compare this value with the average value for 11 September 1972 from the IFYGL study of 1.8. The correspondence of these two values is perhaps fortuitous, since there is no fundamental reason to expect identical lake conditions to exist at the same time period on successive years. However, the fact that such consistent results have been obtained for the same lake on successive years, using the same data analysis approach on different data bases (satellite vs aircraft), is encouraging.

The S190A imagery of Lake Ontario provides an unusual definition of the spatial patterns within the lake. To describe spatial effects with aircraft imagery on the IFYGL program, four lake tracks were flown to give about sixty frames of imagery, each covering about 1.4 miles side to side. Inference of spatial patterns from the aircraft imagery was very difficult and could not be accomplished with the detail of Figure 1.3.

The surface patterns of the satellite data indicate lowest values of blue to green reflectance ratios on the southern shores of the lake, especially near the Genessee River, the Niagara River and the Welland Canal outflow. The northern, western and eastern ends of the lake have correspondingly higher ratio levels.

No red spectral information was utilized in the analyses for two reasons. First, the lake is darkest in the red spectral band, being of the order of a 1% reflector in all but regions of unusually high sediment content. Corrections for flare exposure become extremely critical for such a dark target, with a small error in flare measurement causing a large error in the resulting lake data. The blue and green information was thus considered to provide much more reliable optical characterization. Secondly, all available red bands (both color films and the filtered black and white) were underexposed to the point where the red information was on the shoulder of the red D-log E curve. Such underexposure made accurate sensitometry extremely difficult. In general, we would recommend that future satellite exposures for limnological studies be increased by about one exposure stop.

The correspondence of the satellite and aircraft data depicted in Figure 1.4 is impressive and should be considered a major accomplishment of the program to this point. The capability to reproduce accurately relative values of blue and green lake reflectances is most important for the type of limnological analyses under consideration. The next major milestones to be investigated are (1) a study of satellite accuracy under more complex atmospheric conditions which vary more rapidly within the spatial extent of the image; and (2) completion of the final analysis step which is inference of classical optical data from the satellite data. Both tasks are currently underway.

3.0 CONCLUSIONS

The most useful optical parameter for remote sensing analyses of lakes is the relative value of the blue and green reflectances of the lake. Variations in the ratio of blue to green lake reflectance can be correlated with variations of important optical and biological parameters measured from surface vessels. Determinations of the ratio of blue to green lake reflectance from the S190A color imagery are in excellent agreement with values obtained from small scale color imagery from aircraft, and the accuracy of the satellite values is within the accuracy required for extrapolation of satellite data to surface optical data. The satellite data have a significant advantage over the aircraft imagery in the ability to depict surface patterns within a large lake and in the ability to compare a number of smaller lakes on the same frame of imagery.

The prime characteristic of the S190 imagery which is responsible for the measurement accuracy is the resolution capability of the experiment. The two most desirable refinements to the S190 experiment would be increased spatial resolution and repetitive coverage on a regular basis. The increase in resolution would permit more accurate data processing under more complicated atmospheric conditions. Regular overflights would add the important aspect of temporal information to the water quality analyses.

REFERENCES

1. Optical Properties of Lake Ontario Waters, National Science Foundation Grant No. GA-37768.

2. K. R. Piech, "International Field Year on the Great Lakes: Optical Properties of Lake Ontario Waters", Calspan Corporation Report No. KS-5108-M-1, November 1972.

3. "ERTS Image Processing System Performance Prediction and Product Quality Evaluation Techniques", NASA Contract NAS5-20366.

4. K. R. Piech and J. E. Walker, "Aerial Color Analyses of Water Quality", Journal of the Surveying and Mapping Division, ASCE, Vol. 97, No. SU2, November 1971, pp. 185-197.

5. K. R. Piech and J. E. Walker, "Thematic Mapping of Flooded Acreage", Photogrammetric Engineering, Vol. 38, November 1972, pp. 1081-1090.

6. K. R. Piech and J. E. Walker, "Interpretation of Soils", Photogrammetric Engineering, Vol. 40, January 1974, pp. 87-94.

7. P. G. Smith, K. R. Piech and J. E. Walker, "Special Color Analysis Techniques", to appear in Photogrammetric Engineering.